US007834369B2

(12) **United States Patent**
Yao et al.

(10) **Patent No.: US 7,834,369 B2**
(45) **Date of Patent: Nov. 16, 2010**

(54) **LIGHT-EMITTING DEVICE HAVING A ROUGHENED SURFACE WITH DIFFERENT TOPOGRAPHIES**

(75) Inventors: **Chiu-Lin Yao**, Hsinchu (TW); **Ta-Cheng Hsu**, Hsinchu (TW)

(73) Assignee: **Epistar Corporation**, Hsinchu (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **12/230,054**

(22) Filed: **Aug. 22, 2008**

(65) **Prior Publication Data**

US 2009/0050930 A1 Feb. 26, 2009

(30) **Foreign Application Priority Data**

Aug. 23, 2007 (TW) .... 96131320 A

(51) **Int. Cl.**
H01L 33/22 (2010.01)
(52) **U.S. Cl.** **257/95**; 257/98; 257/E33.074
(58) **Field of Classification Search** 257/E33.074
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,791,117 B2 * 9/2004 Yoshitake et al. 257/94
7,180,088 B2 2/2007 Sugawara
2006/0204865 A1 * 9/2006 Erchak et al. 430/7
2008/0191190 A1 * 8/2008 Tsai et al. 257/13

FOREIGN PATENT DOCUMENTS

CN 1674306 A 9/2005

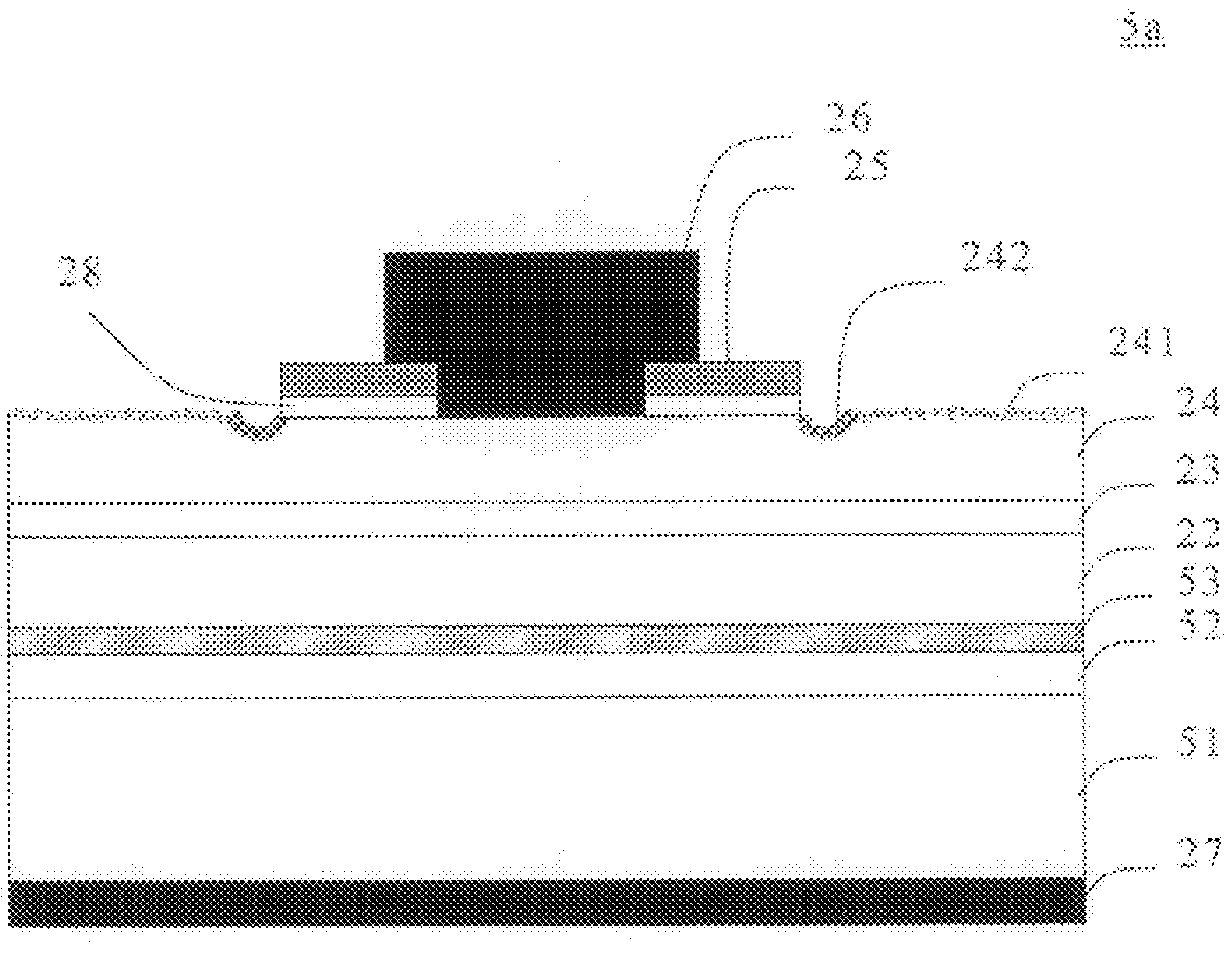
* cited by examiner

Primary Examiner—Stephen W Smoot
(74) *Attorney, Agent, or Firm*—Bacon & Thomas, PLLC

(57) **ABSTRACT**

This invention provides an optoelectronic semiconductor device having a rough surface and the manufacturing method thereof. The optoelectronic semiconductor device comprises a semiconductor stack having a rough surface and an electrode layer overlaying the semiconductor stack. The rough surface comprises a first region having a first topography and a second region having a second topography. The method comprises the steps of forming a semiconductor stack on a substrate, forming an electrode layer on the semiconductor stack, thermal treating the semiconductor stack, and wet etching the surface of the semiconductor stack to form a rough surface.

24 Claims, 10 Drawing Sheets



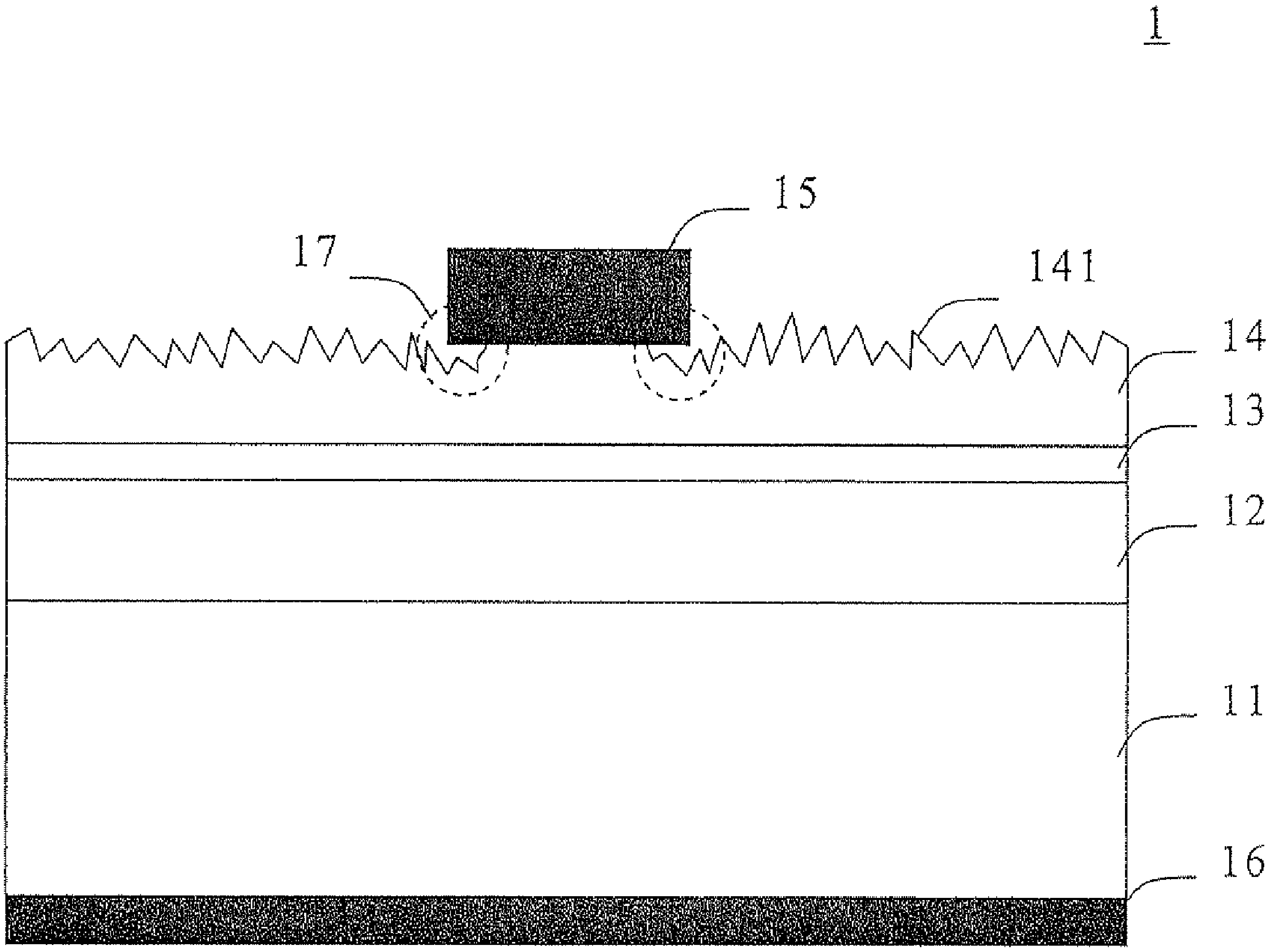


FIG. 1
(PRIOR ART)

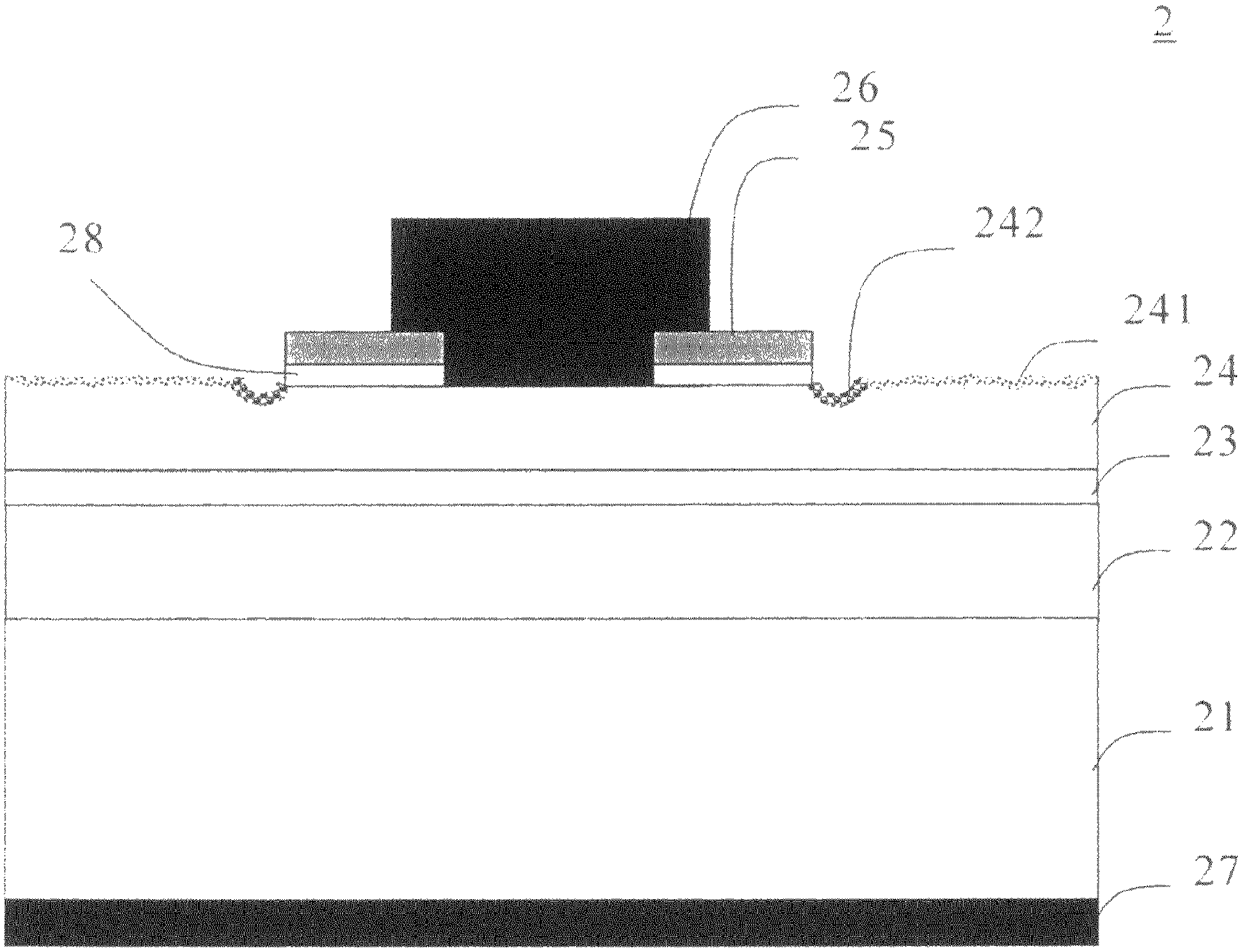


FIG. 2A

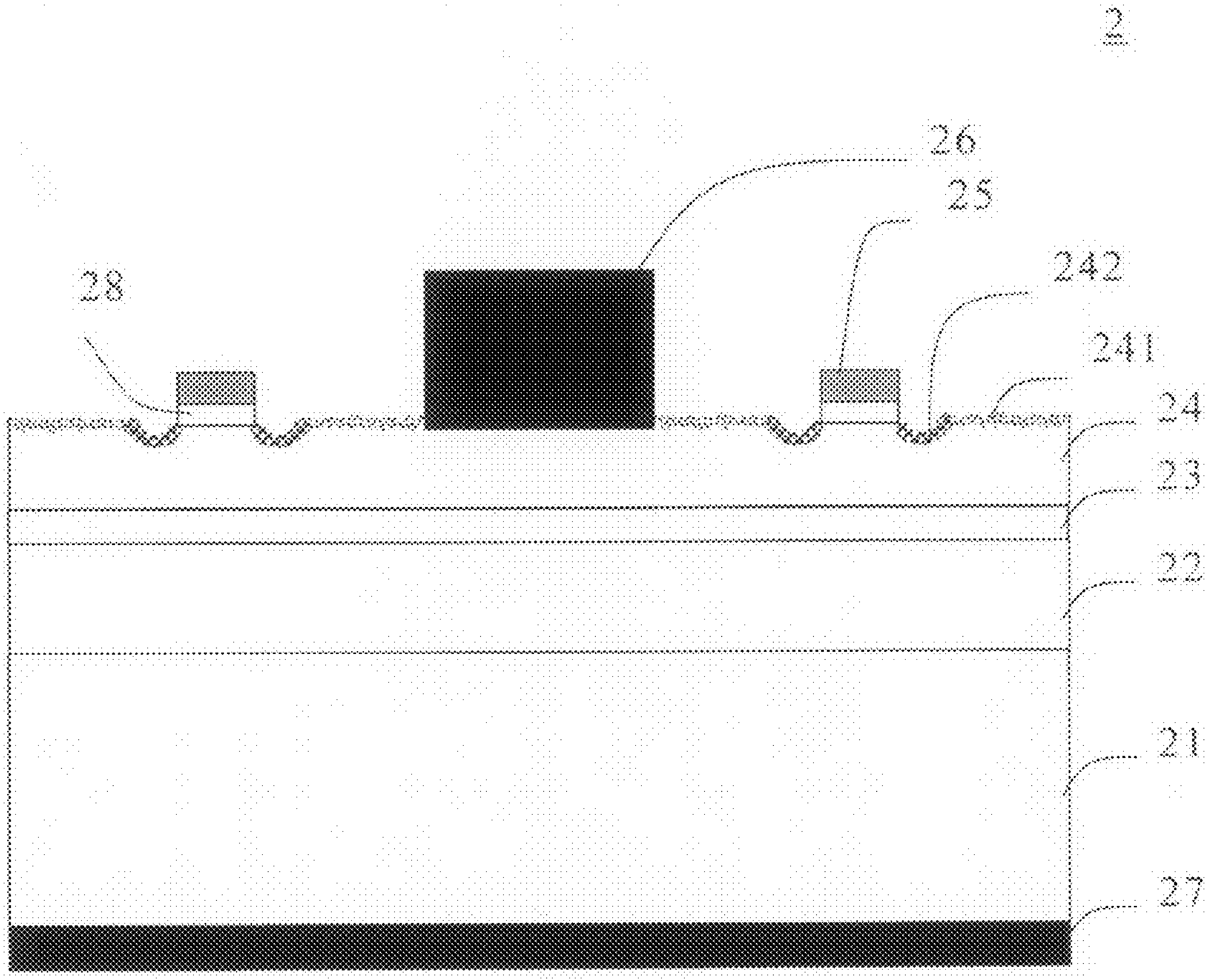


FIG. 2B

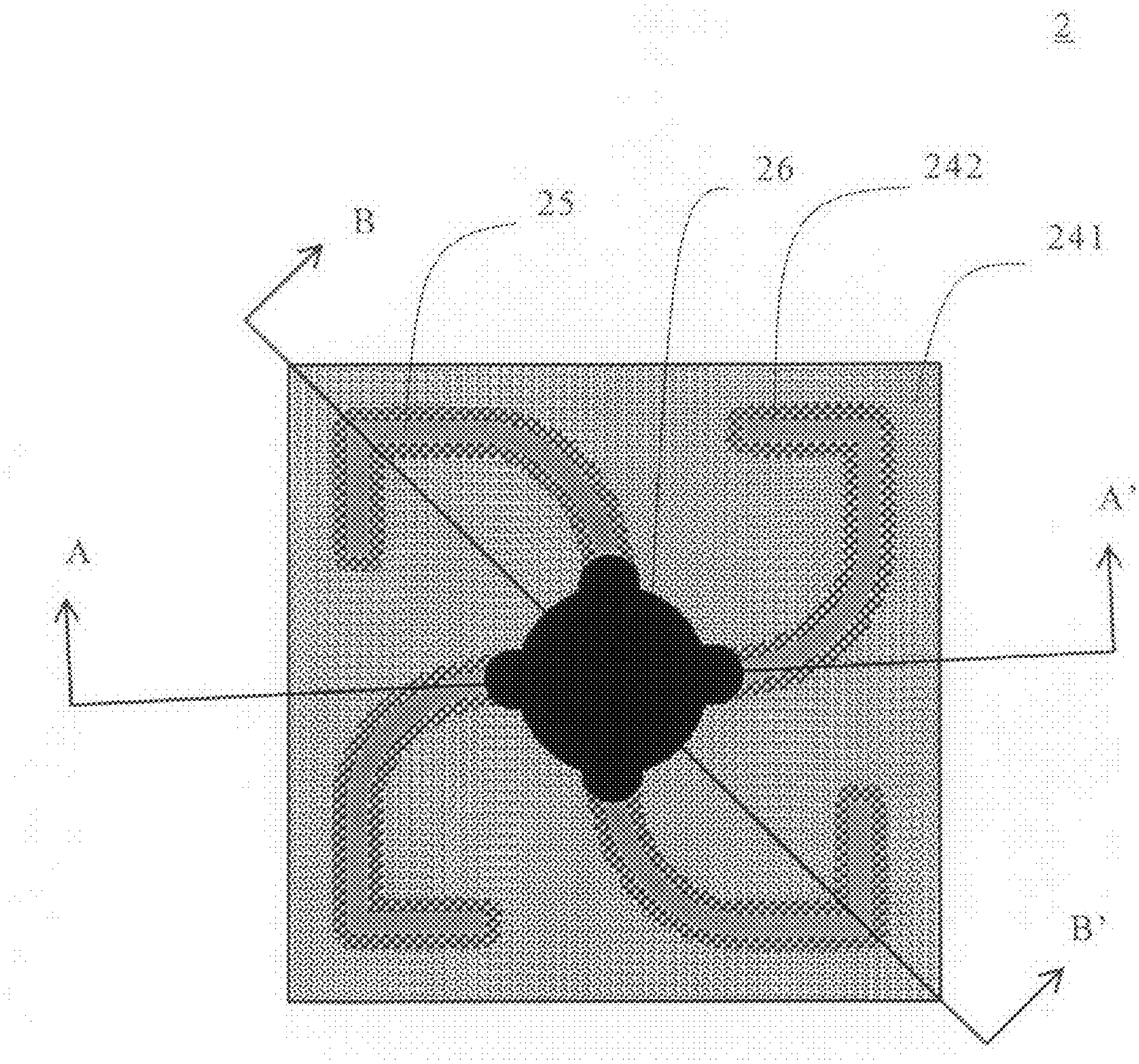


FIG. 2C

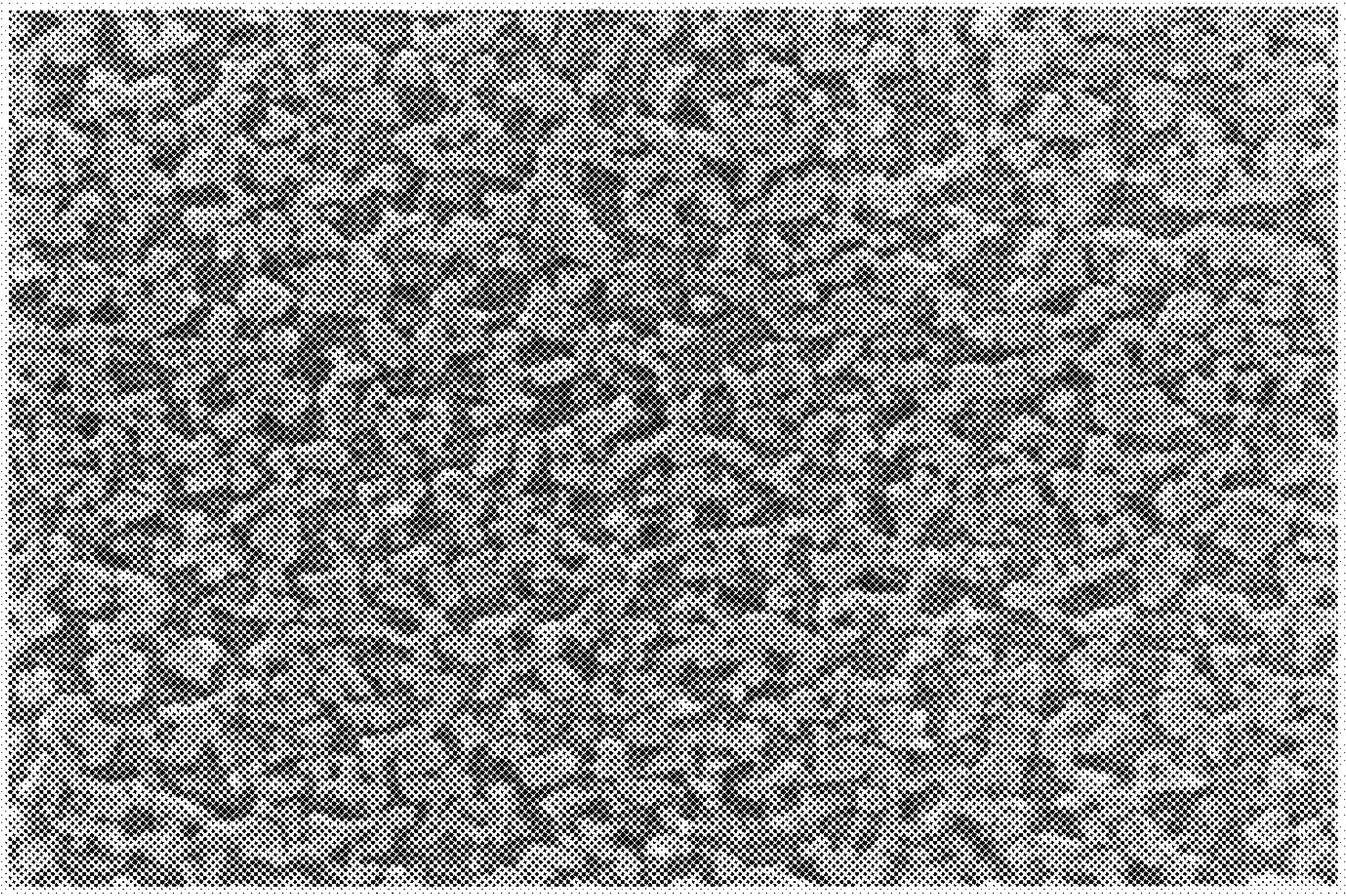


FIG. 3A

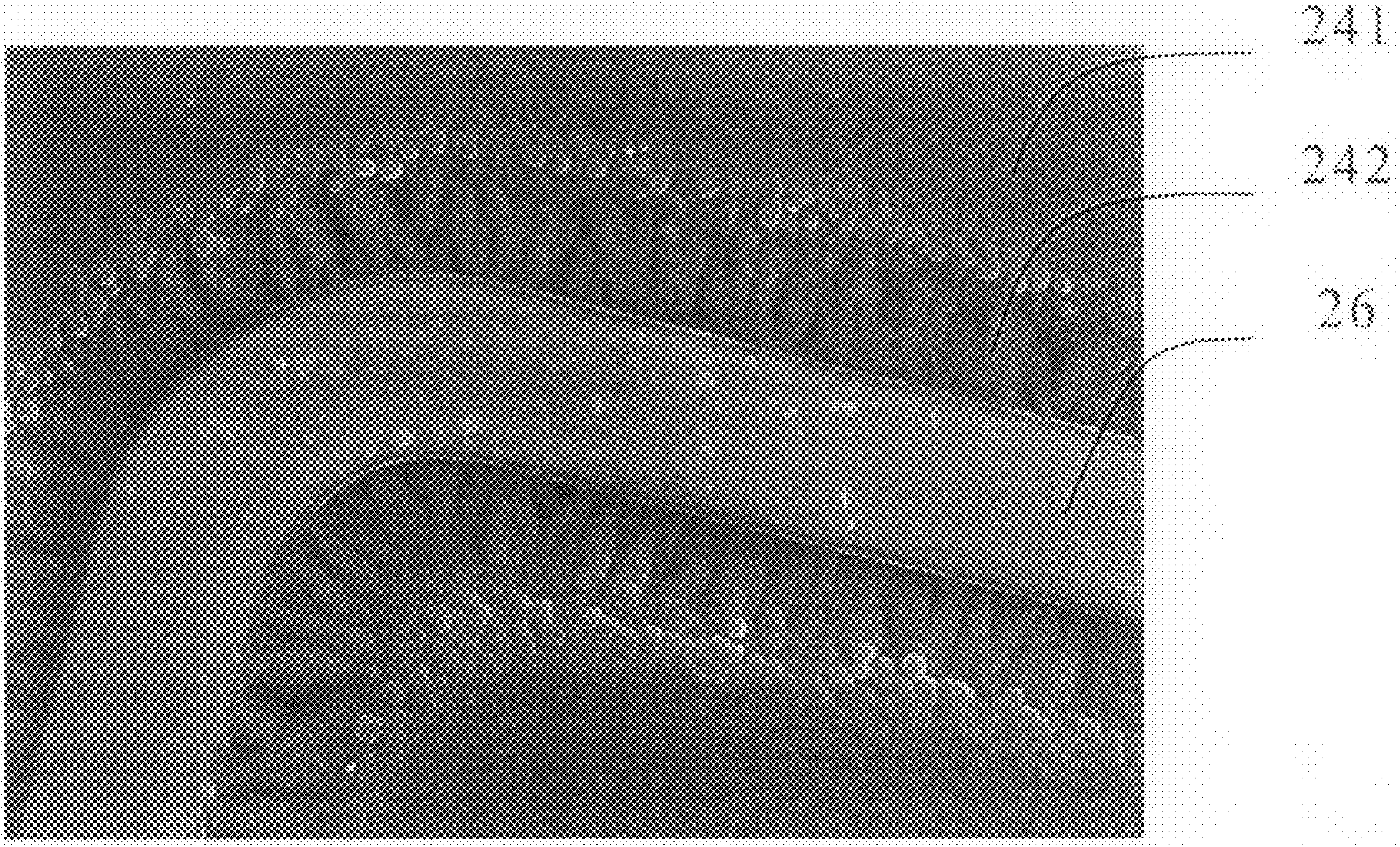


FIG. 3B

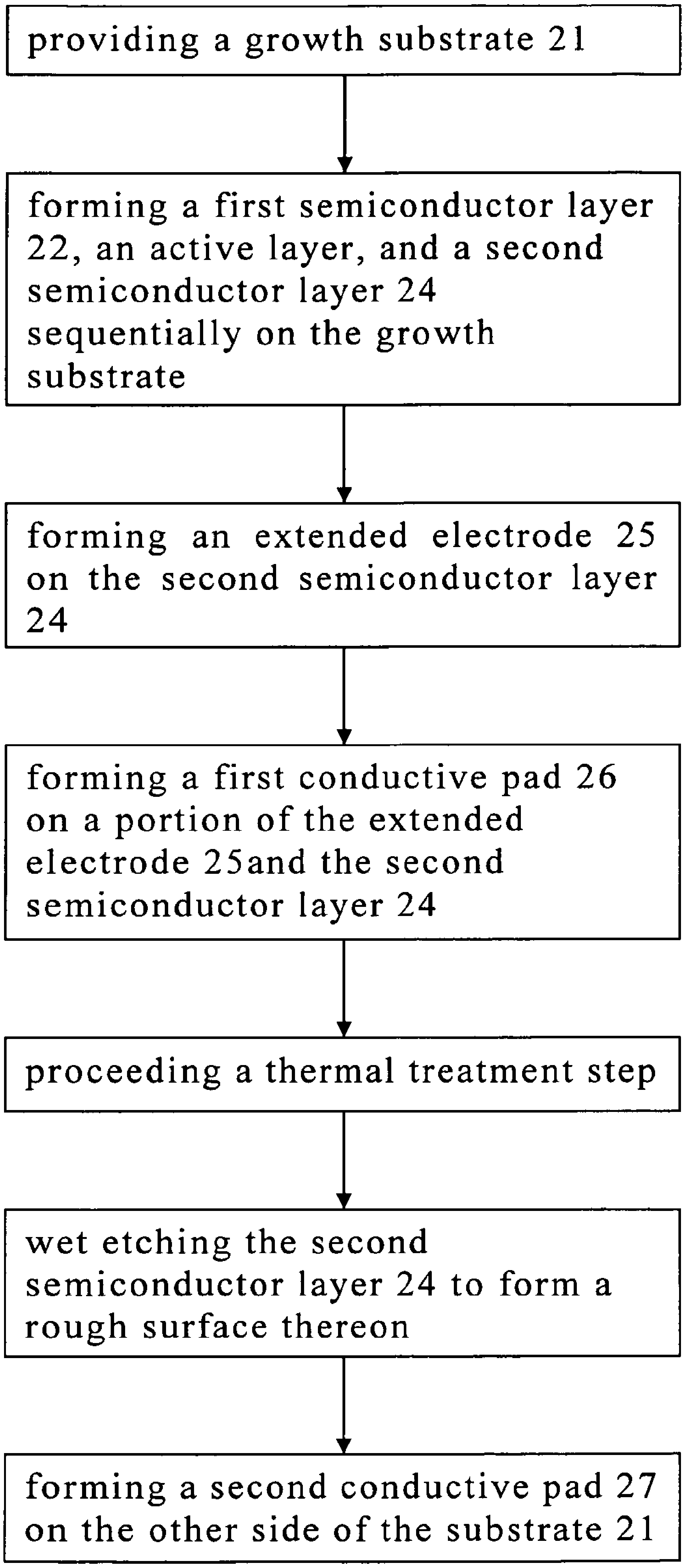

providing a growth substrate 21
forming a first semiconductor layer 22, an active layer, and a second semiconductor layer 24 sequentially on the growth substrate
forming an extended electrode 25 on the second semiconductor layer 24
forming a first conductive pad 26 on a portion of the extended electrode 25and the second semiconductor layer 24
proceeding a thermal treatment step
wet etching the second semiconductor layer 24 to form a rough surface thereon
forming a second conductive pad 27 on the other side of the substrate 21

FIG. 4

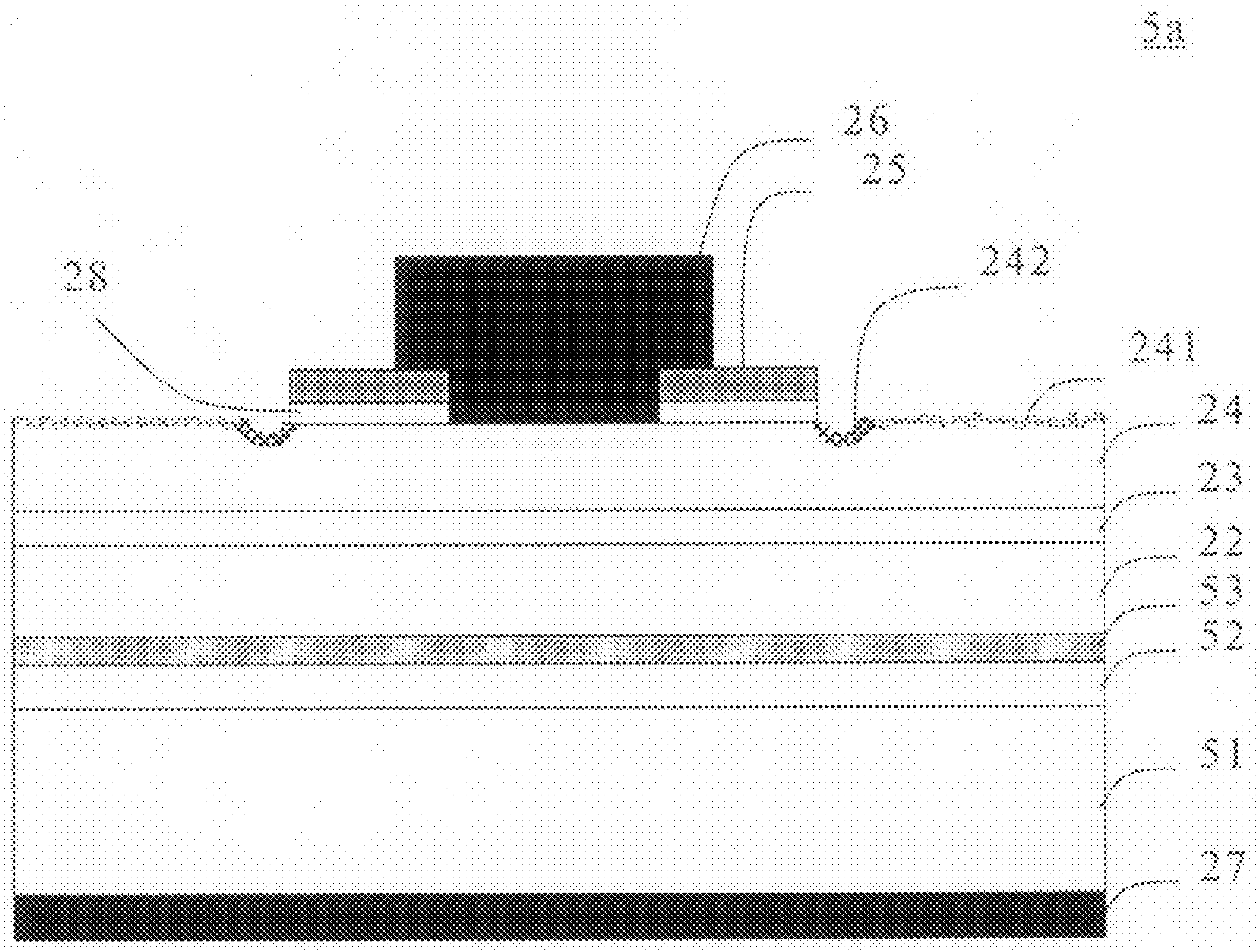


FIG. 5A

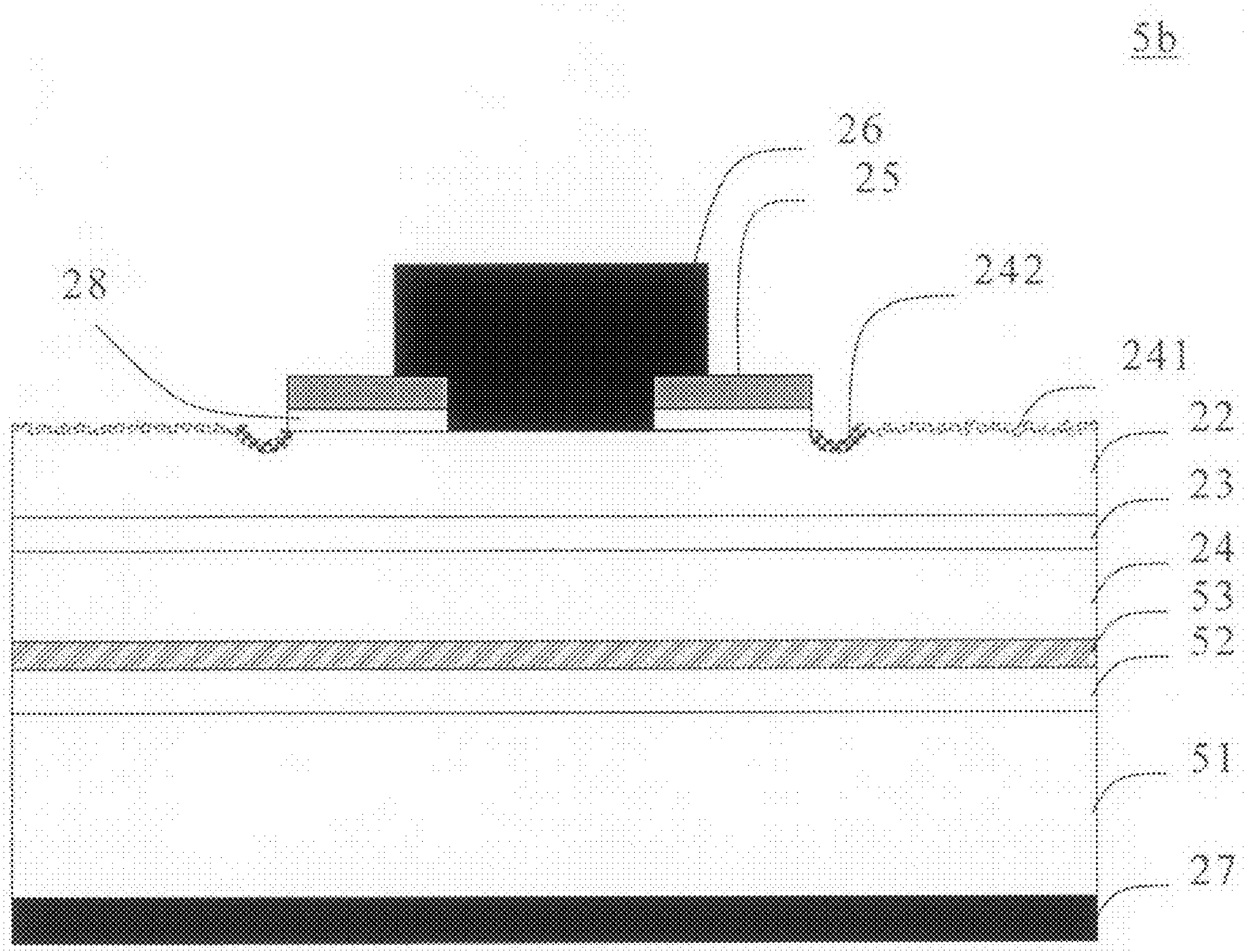


FIG. 5B

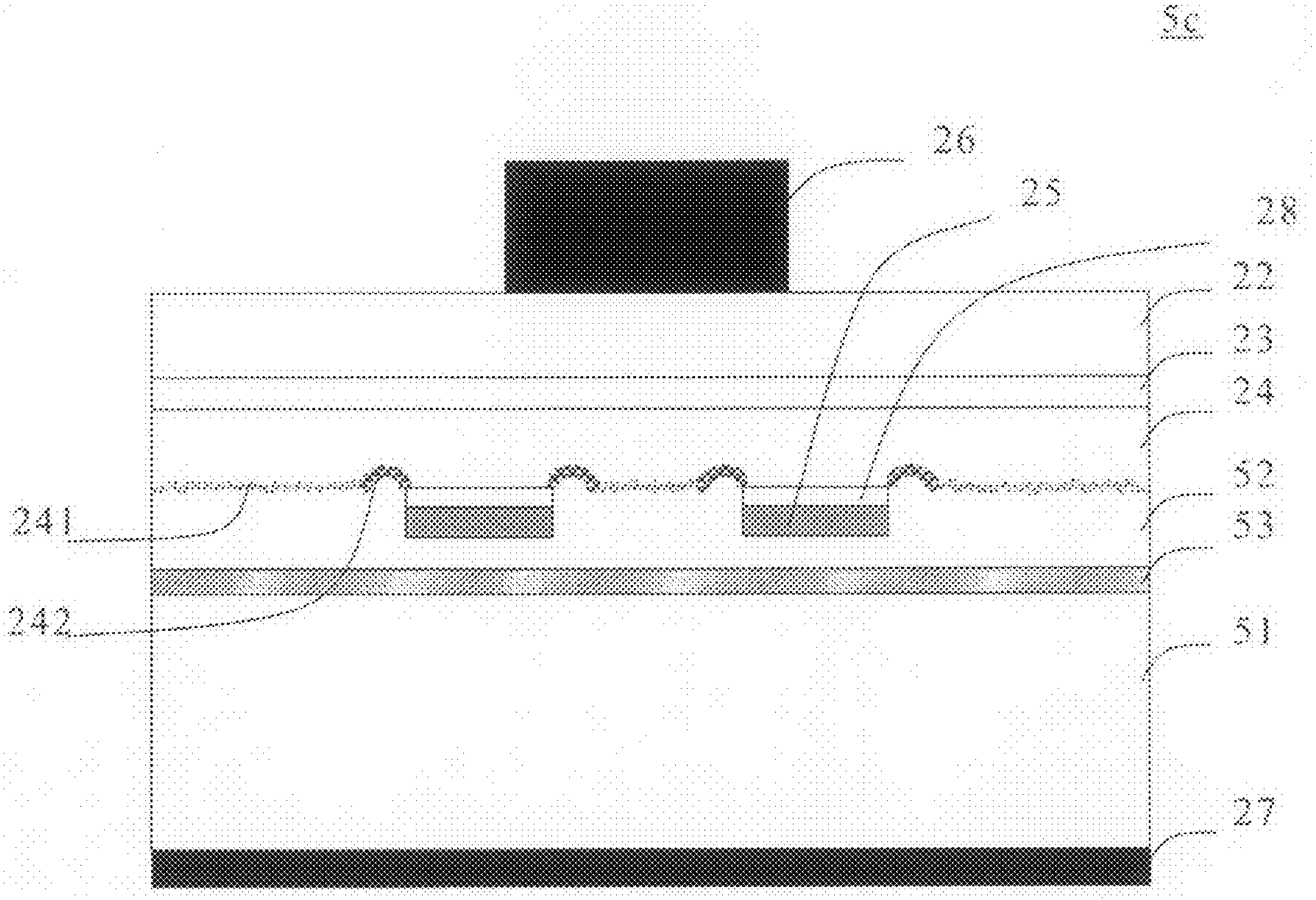


FIG. 5C

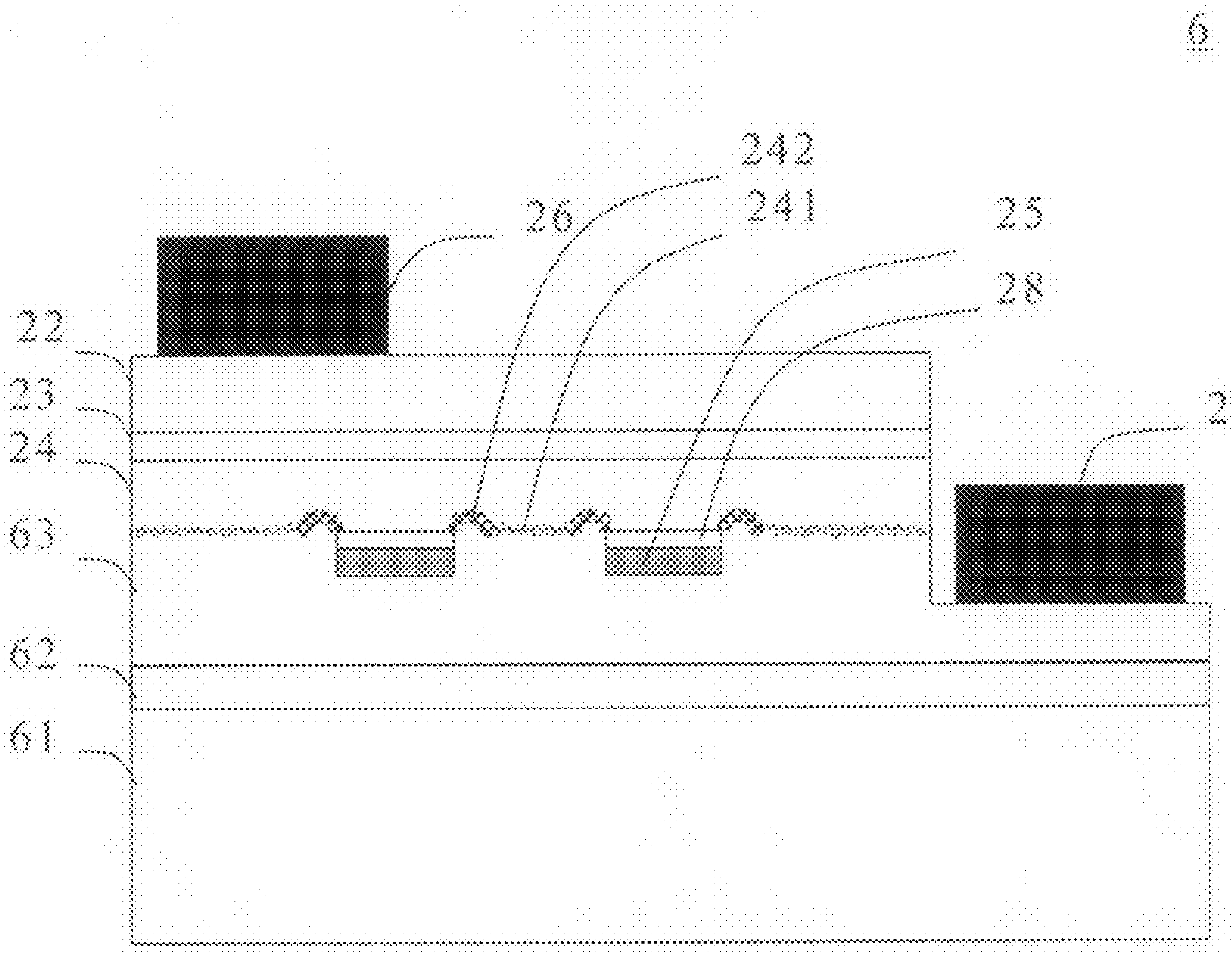


FIG. 6

LIGHT-EMITTING DEVICE HAVING A ROUGHENED SURFACE WITH DIFFERENT TOPOGRAPHIES

REFERENCE TO RELATED APPLICATION

The present application claims the right of priority based on Taiwan Application Ser. No. 096131320, filed Aug. 23, 2007, the disclosure of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

This invention relates to a semiconductor optoelectronic device having a rough surface and the manufacturing method thereof.

BACKGROUND OF THE DISCLOSURE

Surface roughening is one of the efficient ways to improve light extraction efficiency of a light-emitting device. Roughening the substrate or the upmost semiconductor layer into irregular protrusions/depressions to scatter incident light impinging on the roughened surface is an example to improve light extraction efficiency. Roughening surface can be achieved by known processes like mechanically polishing or reactive-ion-etching (RIE). Another feasible way is performed by wet etching the wafer immersed in an etching solution for certain duration. The surface is roughened by different etching rates of the etching solution versus different exposed crystal planes of the surface. The roughened surface of the light-emitting device, as shown in FIG. **1**, is formed by wet etching. The light-emitting device comprises a growth substrate **11**, an n-type semiconductor layer **12**, an active layer **13**, a p-type semiconductor **14**, a p-side conductive pad, and an n-side conductive pad. The surface of the p-type semiconductor layer **14** is wet-etched to form a roughened surface. An undercut **17** is formed due to lateral etching in the border between the p-side conductive pad **16** and the p-type semiconductor layer **14**. The contact area between the p-side conductive pad **16** and the p-type semiconductor layer **14** is therefore reduced such that the device reliability is easily failed or the p-side conductive pad **16** is easily peeled off by the stress. Besides, the uniformity of the roughened surface formed by the conventional wet etching method is not good enough to keep the product stable.

Another conventional way to prevent the light-emitting device from reliability failure or pad peeling is to form the roughened surface before forming the conductive pad, but the contact resistance between the conductive pad and the roughened surface of the underlying layer becomes high and therefore downgrade the device performance. Besides, the resulted surface of the conductive pad is uneven and therefore obstructs the wire-bonding yield.

SUMMARY OF THE DISCLOSURE

One aspect of the present invention is to provide an optoelectronic semiconductor device comprising a substrate; a semiconductor stack further comprising a first semiconductor layer of a first conductivity, an active layer, and a second semiconductor layer of a second conductivity; and an electrode layer formed on the second semiconductor layer; wherein the first and/or second semiconductor layer having a rough surface comprising a first region having a first topography and a second region having a second topography.

Another aspect of the present invention is to provide a method for forming a rough surface on a semiconductor layer of an optoelectronic semiconductor device. The method comprises the steps of forming a semiconductor stack on a substrate; forming an electrode layer on the semiconductor stack; heat treating the semiconductor stack and the electrode layer; and wet etching the surface of the semiconductor stack to form a rough surface.

The optoelectronic semiconductor device comprises light-emitting device or photovoltaic device.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram showing a light-emitting device according to a conventional structure.

FIG. **2**A to FIG. **2**B are schematic diagrams showing one embodiment of a light-emitting device in accordance with the present invention.

FIG. **2**C is a schematic diagram showing the top view of the light-emitting device in FIG. **2**A or FIG. **2**B.

FIG. **3**A is an SEM picture showing the first topography of the rough surface formed in accordance with the present invention.

FIG. **3**B is an SEM picture showing the second topography of the rough surface formed in accordance with the present invention.

FIG. **4** is a flow chart showing the manufacturing method in accordance with the present invention.

FIG. **5**A to FIG. **5**C are schematic diagrams showing a light-emitting device comprising a bonding structure in accordance with the present invention.

FIG. **6** is a schematic diagram showing a light-emitting device comprising a lateral structure in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **2**A to FIG. **2**C show a light-emitting device **2** in accordance with the present invention. FIG. **2**C is a top view of the light-emitting device **2**, and FIG. **2**A and FIG. **2**B are the cross-section views along with AA' and BB' respectively. As shown in FIG. **2**A and FIG. **2**B, the light-emitting device **2** comprises a substrate **21** having a top surface and a bottom surface; a first semiconductor layer **22** of a first conductivity overlaying the substrate; an active layer **23** overlaying the first semiconductor layer **22**; a second semiconductor layer **24** of a second conductivity comprising a rough surface overlaying the active layer **23**; an extended electrode layer **25** overlaying the second semiconductor layer **24**; a first conductive pad **26** overlaying a portion of the extended electrode layer **25** and a portion of the second semiconductor layer **24**; and a second conductive pad **27** underlying the bottom surface of the substrate **21**. The material of the first semiconductor layer **22**, the active layer **23**, or the second semiconductor layer **24** comprises n-type or p-type $Al_pGa_qIn_{(1-p-q)}P$ or $Al_xIn_yGa_{(1-x-y)}N$ ($0 \leqq p, q, x, y \leqq 1$; $(p+q) \leqq 1$; $(x+y) \leqq 1$). The first semiconductor layer **22** comprises a first conductivity type cladding layer, and the second semiconductor layer **24** comprises a second conductivity type cladding layer. The extended electrode layer **25** is a current spreading layer having a pattern extended toward the surroundings of the light-emitting device for spreading current as shown in FIG. **2**C. The first conductive pad **26** is a bonding pad covering and electrically coupled to a portion of the extended electrode layer **25**. The material of the extended electrode layer **25** comprises single or multi-layer of metal or metal alloy such as Ge/Au. The material of the conductive pad **26** comprises multilayer of metal such as Cr/Au. In one embodiment, the light-emitting device **2** further comprises an ohmic contact layer **28** interposed between the second semiconductor layer **24** and the extended electrode layer **25**. The ohmic contact layer **28** comprises a semiconductor layer with a higher doping concentration than that of the second semiconductor layer **24**, such as GaAs having Si-doping concentration higher than 10^{18}cm^{-3}. The conductivity type of the ohmic contact layer **28** can be the same as or different to the second semiconductor layer **24** and form an ohmic contact with the second semiconductor layer **24**. In a preferred embodiment, the ohmic contact layer **28** is formed only under the region covered by the extended electrode layer **25**. The first conductivity type comprises n-type or p-type, and the second conductivity type is different from the first conductivity type.

The rough surface comprises a first region **241** having a first rough topography and a second region **242** having a second rough topography. The first region and the second region comprise a plurality of depressions and protrusions. The dimension of the first rough topography is smaller than that of the second rough topography. In an embodiment of the present invention, the distance between the neighboring depressions or the distance between the neighboring protrusions of the first rough topography is around 0.1 to 0.5 micron. The depth of at least one of the depressions or the height of at least one protrusion of the first rough topography is around 0.1 to 0.5 micron. The distance between the neighboring depressions or the distance between the neighboring protrusions of the second rough topography is around 1 to 10 microns. The depth of at least one of the depressions or the height of at least one of the protrusions of the second rough topography is around 0.5 to 2 microns. The first rough topography as shown in FIG. **3**A is a randomly rough surface having a plurality of depressions and protrusions. The second rough topography as shown in FIG. **3**B is a wave-shape surface. The second region **242** having the second topography is adjacent to and surrounds the extended electrode layer **25**, and therefore separating the extended electrode layer **25** from the first region **241** having the first rough topography. The level, i.e. the average altitude of the surface, of the second region **242** is about 0.5 to 2 microns lower than that of the first region **241**. The cross-sectional shape of the second region **242** is a curve such that the interface between the extended electrode layer **25** and the second region **242** is outward oblique from the extended electrode layer **25** to prevent from undercut and further improve the reliability of the device and the peeling-off issue of the electrode layer.

FIG. **4** discloses a manufacturing method for forming the above-mentioned light-emitting diode **2**. The method comprises the steps of:

1. providing a growth substrate **21**;
2. forming a first semiconductor layer **22**, an active layer, and a second semiconductor layer **24** sequentially on the growth substrate;
3. forming an extended electrode layer **25** on the second semiconductor layer **24**;
4. forming a first conductive pad **26** on a portion of the extended electrode layer **25** and the second semiconductor layer **24**;
5. proceeding a thermal treatment step, such as rapid thermal annealing (RTA);
6. wet etching the second semiconductor layer **24** by an etching solution comprising HF,HNO_3,CH_3COOH, and iodine under a low temperature condition from room temperature to 60° C. to form a rough surface thereon, wherein the features of the rough surface is described in the previous embodiments, such as FIG. **3**A and FIG. **3**B;
7. forming a second conductive pad **27** on the other side of the substrate **21**.

The structure formed by the method is shown in FIG. **2**A or FIG. **2**B.

FIG. **5**A shows another embodiment of the present invention. The light-emitting device **5***a* as shown in FIG. **5**A is similar to the light-emitting device **2**. The distinction is that the substrate **51** of the light-emitting device **5***a* is a conductive substrate. The substrate **51** can also be a transparent or opaque conductive substrate. It is also preferred that the substrate is a conductive substrate comprising a material having high thermal conductivity not lower than 100 W/cm·° C., such as Si, Cu, or diamond. The conductive substrate **51** is coupled to the first semiconductor layer **22** by a conductive connecting layer **52**. The conductive connecting layer **52** comprises a transparent conductive layer or a conductive adhesive layer. The material of the transparent conductive layer comprises transparent conductive oxide, such as indium tin oxide (ITO), zinc oxide (ZnO), or thin metal. The material of the conductive adhesive layer comprises silver paste or solder metal. The light-emitting device **5***a* further comprises a reflecting layer **53** formed between the conductive connecting layer **52** and the first semiconductor layer **22** for reflecting the light emitted from the active layer **23** and preventing from being absorbed by the conductive substrate **51** if the conductive substrate **51** is opaque.

The manufacturing method for forming the light-emitting device **5***a* comprises the steps of:

1. providing a growth substrate (not shown);
2. forming a first semiconductor layer **22**, an active layer **23**, and a second semiconductor layer **24** sequentially on the growth substrate;
3. bonding a temporary substrate (not shown) to the second semiconductor layer **24**;
4. removing the growth substrate to expose one surface of the first semiconductor layer **22**;
5. forming a reflecting layer **53** on the exposed surface of the first semiconductor layer **22**;
6. forming a conductive connecting layer **52** on a conductive substrate **51**;
7. bonding the conductive substrate **51** with the conductive connecting layer **52** to the reflecting layer **53**;
8. removing the temporary substrate to expose one surface of the second semiconductor layer **24**
9. forming an extended electrode layer **25** on the exposed surface of the second semiconductor layer **24**;
10. forming a first conductive pad **26** on a portion of the extended electrode layer **25** and the second semiconductor layer **24**;
11. proceeding a thermal treatment step, such as rapid thermal annealing (RTA);
12. wet etching the second semiconductor layer **24** to form a rough surface thereon, wherein the features of the rough surface is described in the previous embodiments, such as FIG. **3**A and FIG. **3**B;
13. forming a second conductive pad **27** on the other side of the conductive substrate **51**.

FIG. **5**B shows another embodiment of the present invention. The light-emitting device **5***b* as shown in FIG. **5**B is similar to the light-emitting device **5***a* mentioned above. The distinction is that the rough surface is formed on the first semiconductor layer **22**.

The manufacturing method for forming the light-emitting device **5***b* comprises the steps of:

1. providing a growth substrate (not shown);
2. forming a first semiconductor layer **22**, an active layer **23**, and a second semiconductor layer **24** sequentially on the growth substrate;
3. forming a reflecting layer **53** on the second semiconductor layer **24**;
4. forming a conductive connecting layer **52** on a conductive substrate **51**;
5. bonding the conductive substrate **51** with the conductive connecting layer **52** to the reflecting layer **53**;
6. removing the growth substrate to expose one surface of the first semiconductor layer **22**;
7. forming an extended electrode layer **25** on the exposed surface of the first semiconductor layer **22**;
8. forming a first conductive pad **26** on a portion of the extended electrode layer **25** and the first semiconductor layer **22**;
9. proceeding a thermal treatment step, such as rapid thermal annealing (RTA);
10. wet etching the first semiconductor layer **22** to form a rough surface thereon, wherein the features of the rough surface is described in the previous embodiments, such as FIG. **3**A and FIG. **3**B;
11. forming a second conductive pad **27** on the other side of the conductive substrate **51**.

FIG. **5**C shows another embodiment of the present invention. The distinction between the light-emitting device **5***c* as shown in FIG. **5**C and the above-mentioned embodiment is that the rough surface is formed inside the light-emitting device **5***c* instead of on the outer surface of the light-emitting device.

The manufacturing method for forming the light-emitting device **5***c* comprises the steps of:

1. providing a growth substrate (not shown);
2. forming a first semiconductor layer **22**, an active layer **23**, and a second semiconductor layer **24** sequentially on the growth substrate;
3. forming an extended electrode layer **25** on the second semiconductor layer **24**;
4. proceeding a thermal treatment step, such as rapid thermal annealing (RTA);
5. wet etching the second semiconductor layer **24** to form a rough surface thereon, wherein the features of the rough surface is described in the previous embodiments, such as FIG. **3**A and FIG. **3**B;
6. forming a reflecting layer **53** on a conductive substrate **51**;
7. forming a conductive connecting layer **52** on the reflecting layer **53**;
8. bonding the extended electrode layer **25** and the second semiconductor layer **24** to the reflecting layer **53** by the conductive connecting layer **52**;
9. removing the growth substrate to expose one surface of the first semiconductor layer **22**;
10. forming a first conductive pad **26** on a portion of the exposed surface of the first semiconductor layer **22**;
11. forming a second conductive pad **27** on the other side of the conductive substrate **51**.

FIG. **6** shows a light-emitting device having a lateral structure as another embodiment of the present invention. The light-emitting device **6** and the light-emitting device **5***c* each comprises a rough surface inside the device. The distinction is that the light-emitting device **6** further comprises a transparent conductive layer **63** for electrically coupling the first conductive pad **26** to the second conductive pad **27** and bonding to a transparent substrate **61** by a transparent adhesive layer **62**. At least one of the transparent adhesive layer **62** and the transparent substrate **61** comprises an insulating layer or an insulating structure for electrically isolating the transparent substrate **61** from the transparent conductive layer **63**, such as forming an insulating layer on a transparent conductive substrate. The material of the transparent conductive layer **63** comprises indium tin oxide (ITO), zinc oxide (ZnO) or thin metal. The material of the transparent adhesive layer **62** comprises polyimide (PI), benzocyclobutene (BCB), perfluorocyclobutane (PFCB), epoxy resin, or silicone. The material of the transparent substrate **61** comprises sapphire, glass GaP, SiC, or CVD diamond. The light-emitting device **6** comprises a transparent bonding structure and a transparent substrate to be capable of extracting light from the substrate, and then improve the light extraction efficiency.

The manufacturing method for forming the light-emitting device **6** comprises the steps of:

1. providing a growth substrate (not shown);
2. forming a first semiconductor layer **22**, an active layer **23**, and a second semiconductor layer **24** sequentially on the growth substrate;
3. forming an extended electrode layer **25** on the second semiconductor layer **24**;
4. proceeding a thermal treatment step, such as rapid thermal annealing (RTA);
5. wet etching the second semiconductor layer **24** to form a rough surface thereon, wherein the features of the rough surface is described in the previous embodiments, such as FIG. **3**A and FIG. **3**B;
6. forming a transparent conductive layer **63** the extended electrode layer **25** and the second semiconductor layer **24**;
7. forming a transparent adhesive layer **62** on a transparent substrate **61**;
8. bonding the transparent conductive layer **63** to the transparent substrate **61** by the transparent adhesive layer **62**;
9. removing the growth substrate to expose one surface of the first semiconductor layer **22**;
10. removing a part of the first semiconductor layer **22**, the active layer **23**, the second semiconductor layer **24**, and the transparent conductive layer **63** to expose a portion of the transparent conductive layer **63**;
11. forming a first conductive pad **26** on the first semiconductor layer **22**;
12. forming a second conductive pad **27** on the exposed portion of the transparent conductive layer **63**.

Another alternative embodiment for step **10** to step **12** of the method for forming the light-emitting device **6** is to remove a part of the first semiconductor layer **22**, the active layer **23**, the second semiconductor layer **24** to expose a portion of the second semiconductor layer **24**, and form the second conductive pad **27** on the exposed portion of the second semiconductor layer **24**.

According to the various embodiments described as above, it is still under the scope of the present invention to form the featured rough surface on both of the first semiconductor layer and the second semiconductor layer to further enhance the light extraction efficiency.

It should be noted that the proposed various embodiments are not for the purpose to limit the scope of the invention. Any possible modifications without departing from the spirit of the invention may be made and should be covered by the invention.

What is claimed is:

1. An optoelectronic semiconductor device comprising:

a substrate;

a semiconductor stack having a rough surface;

a transparent adhesive layer between the semiconductor stack and the substrate; and

an electrode layer overlaying the semiconductor stack;

wherein the rough surface comprises a first region having a first rough topography and a second region having a second rough topography different from the first rough topography.

2. The optoelectronic semiconductor device according to claim **1**, wherein the second region is adjacent to the electrode layer.

3. The optoelectronic semiconductor device according to claim **2**, wherein the second region surrounds the electrode layer.

4. The optoelectronic semiconductor device according to claim **1**, wherein the level of the second region is lower than the level of the first region.

5. The optoelectronic semiconductor device according to claim **1**, wherein the dimension of the second region is larger than the dimension of the first region.

6. The optoelectronic semiconductor device according to claim **1**, wherein the electrode layer comprises an extended portion.

7. The optoelectronic semiconductor device according to claim **6**, wherein the second region is adjacent to the extended portion.

8. The optoelectronic semiconductor device according to claim **1**, further comprising an ohmic contact layer formed between the electrode layer and the semiconductor stack.

9. The optoelectronic semiconductor device according to claim **1**, wherein the first rough topography and/or the second rough topography is a random rough surface.

10. The optoelectronic semiconductor device according to claim **1**, wherein the electrode layer comprises Ge/Au.

11. The optoelectronic semiconductor device according to claim **1**, wherein the semiconductor stack comprises GaP-based or GaN-based semiconductor material.

12. The optoelectronic semiconductor device according to claim **1**, wherein the transparent adhesive layer is non-conductive.

13. An optoelectronic semiconductor device comprising:

a substrate;

a semiconductor stack having a rough surface;

a conductive adhesive layer between the semiconductor stack and the substrate; and

an electrode layer overlaying the semiconductor stack;

wherein the rough surface comprises a first region having a first rough topography and a second region having a second rough topography different from the first rough topography.

14. The optoelectronic semiconductor device according to claim **13**, wherein the conductive adhesive layer comprises silver paste or solder metal.

15. The optoelectronic semiconductor device according to claim **13**, wherein the second region is adjacent to the electrode layer.

16. The optoelectronic semiconductor device according to claim **15**, wherein the second region surrounds the electrode layer.

17. The optoelectronic semiconductor device according to claim **13**, wherein the level of the second region is lower than the level of the first region.

18. The optoelectronic semiconductor device according to claim **13**, wherein the dimension of the second region is larger than the dimension of the first region.

19. The optoelectronic semiconductor device according to claim **13**, wherein the electrode layer comprises an extended portion.

20. The optoelectronic semiconductor device according to claim **19**, wherein the second region is adjacent to the extended portion.

21. The optoelectronic semiconductor device according to claim **13**, further comprising an ohmic contact layer formed between the electrode layer and the semiconductor stack.

22. The optoelectronic semiconductor device according to claim **13**, wherein the first rough topography and/or the second rough topography is a random rough surface.

23. The optoelectronic semiconductor device according to claim **13**, wherein the electrode layer comprises Ge/Au.

24. The optoelectronic semiconductor device according to claim **13**, wherein the semiconductor stack comprises GaP-based or GaN-based semiconductor material.

* * * * *